Comparative analysis of the properties of composite mortar with addition of rubber powder from worn tires

Análise comparativa de propriedades de argamassa mista com adição de pó de borracha de pneus inservíveis

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Abstract

This study compares the performance of two plastering mortars. The first one was produced at a 1:6 proportion of quicklime powder and sand (by volume) and ripened. The second had the same proportion but underwent a water withdrawal process in the oven. The mortars were given the same content of cement, making the proportion 1:1.5:9 (by volume), and the addition of rubber powder from worn tires at the proportions of 6%, 8%, 10% and 12% by aggregate volume. Axial compressive strength, flexural strength, deformation energy, void content, water absorption by capillarity, restrained shrinkage, and tensile bond strength were measured. The results showed that the second mortar, with rubber waste, performed better than the ripened mortar. With a reduction in the absorption of water by capillarity in the restrained shrinkage and in the void content, it maintained the tensile bond strength. The energy of deformation rose, although the compressive strength dropped.

Keywords: Tire waste. Plastering mortar. Capillarity. Deformation.

Resumo

Este estudo compara o desempenho de duas argamassas para revestimento. A primeira, produzida no traço 1:6 de cal virgem e areia (em volume), maturada. A segunda com a mesma argamassa da primeira, mas que passou pelo processo de retirada de água em estufa. As argamassas receberam o mesmo teor de cimento, compondo o traço 1: 1,5: 9 (em volume) e adições de pó de borracha de pneus inservíveis, nas proporções (6%, 8% ,10% e 12%) em volume de agregado. Determinaram-se: as resistências à compressão axial e resistência à tração na flexão, a energia de deformação, o índice de vazios, a absorção de água por capilaridade, a retração restringida e a resistência de aderência à tração. Os resultados mostraram melhor desempenho para a argamassa seca em estufa com resíduos de borracha, em relação à argamassa maturada. Com redução na absorção de água por capilaridade, na retração restringida, no índice de vazios, manteve a resistência de aderência à tração. Embora tenha reduzido a resistência à compressão, apresentou uma maior energia de deformação.

Palavras-chave: *Resíduo de pneus. Argamassa de revestimento. Capilaridade. Deformação.*

Introduction

The tire has a fundamental role in modern society and is irreplaceable in the wheels of vehicles, both in road transportation of cargo and passengers. However, after it becomes useless it turns into an environmental liability. One of the impacts generated by the worn tires refers to their composition, mainly of the non-biodegradable rubber, which can be recycled or reused. Currently in Brazil, about 22 million tires are replaced per year. Of this total, 47 % can be reused and 53 % are considered scrap tires. Of these, only 26,5 % are disposed in an environmentally responsible way, while the remaining 9 million tires are disposed of improperly (GARDIN; FIGUEIRÓ; NASCIMENTO, 2010). Some ways of minimizing the environmental impacts are to reduce the number of tires generated in the first place and to reuse or recycle the materials, reducing the extraction of natural (JANG *et al.*, 1998).

As the tire waste is basically solid rubber, it is classified by the Brazilian norm NBR10004 (ABNT, 2004) as Class II non-hazardous waste and, when ground, it can be easily incorporated in the plastering mortar. Plastering mortar systems are important to buildings, and should meet the following requirements: capacity to absorb deformations, adhesion to the base and low or zero permeability to water (CEOTTO; BANDUK; NAKAMURA, 2005). The evaluation of other properties, such as the compressive and flexural strengths, the tension bond strength, the void content, and the restrained shrinkage is also important.

The capacity to absorb deformation is the ability the material has to deform without rupture when subjected to tensions. The use of aggregates with low deformation modulus has been assumed to be a solution for the design of composites with high strain capacity (TURATSINZE; BONNET; GRANJU, 2007; MIRANDA; SELMO, 2006). A greater tenacity of the material, obtained by the energy of deformation, means a greater capacity to absorb deformation.

The low modulus of deformation of the material should not interfere with properties such as the tensile bond strength (adhesion to the base), nor should it contribute much to the reduction of compressive and flexural strengths.

The permeability can occur by means of pressure infiltration, capillarity, or water vapor diffusion. It is assessed by the capillary absorption of water, which must be lower than the base absorption to provide protection against the passage of rainwater (VALEK; HUGHES; BARTOS, 2000). The mortars produced with a smaller water/binders ratio have capillaries of smaller diameter that are less intercommunicable (STROEVEN; STROEVEN, 2001). Another property, the drying shrinkage, is fundamental to the performance of the coating on the matter of tightness and durability. Concerning retraction, the ideal content and particle size of the aggregate allow the reduction of the paste amount, maintaining adequate workability for use.

To obtain a ready mix that had the advantage of a constant and proper composition of the plastering mortar, Canova (2002) studied the process of water withdrawal in oven from a ripened mortar of lime and sand. From the traditional process in which lime is hydrated and ripened with the sand, the simple mortar was subjected to the process of oven drying. Once the mortar was dried, the blocks were removed and the lumps were broken up. The material was sieved through a 2.4 mm screen and then packaged in double plastic bags. The formation of lumps was not observed after a storage time of 120 days. Thermogravimetric analysis before and after drying and also after the 120 days of storage showed no significant changes in the physicochemical properties of the mortar. Lime maintained its binding properties and the mortar showed improvement in the workability with the increase in incorporated air and kept the water retention and exudation as in the conventional mortar, reduced water absorption and cracking, produced an increase in mechanical strength and did not lead to any significant increase in the deformation modulus.

Rubber, as a highly elastic material, tends to contribute to a better deformation in the plastering mortar, thus improving the performance in relation to cracking. Studies concerning the use of rubber powder from worn tires in cement-based materials are very recent, starting with (ELDIN; SENOUCI, 1993). These researchers found reductions in the mechanical strengths of concrete. Moreover, Topçu (1995) and Toutanji (1996) found that the concrete with the addition of rubber aggregate showed elastic behavior. Hernandes-Olivares and Barluenga (2004) and Güneyisi, Gesoglu and Ozturan (2004), who worked with rubberized concretes containing silica fume, also found sharp drops in the mechanical strength.

Raghavan, Huynh and Ferraris (1998) and Turatsinze, Bonnet and Granju (2005), among others, working with incorporation of rubber aggregates, verified a reduction in the mechanical strength of mortar. Turatsinze, Bonnet and Granju

(2005) gave greater emphasis to the reduction in deformation modulus.

Segre *et al.* (2004) obtained satisfactory results when working with mortar of cement, sand, and rubber and treating the rubber to increase its adhesion to cement paste. Canova, Bergamasco and Angelis Neto (2007) began studies with the addition of rubber powder in plastering mortar.

This study aimed to compare the properties of two types of rendering mortar, one conventional and the other dried in oven, using the addition of 6%, 8%, 10%, and 12% of rubber powder from worn tires. The main focus was on the reduction of cracking in the plastering mortar, as well as on the minimization of environmental problems.

Materials and methods

The materials used in the composition of the plastering mortar were: Class 32 compound Portland cement (CP II Z - 32), common lime powder (CV - C), fine washed river sand, and ground rubber powder from worn tires with a particle diameter of less than 0.5 mm. The characterization of the employed materials is found in Tables 1 to 5.

The results of the chemical assay, Table 4, revealed the presence of heavy metals in the rubber residue, such as plumb and total chrome; however, after the rubber was added to the mortar, the values fell within the standard limits.

Table 1 - **Physical and mechanical properties of Portland cement (CP II Z - 32)**

Determination		Result	Method
Setting time	Start	2 hours 50 minutes	NBR 7215 (ABNT, 1995)
	End	7 hours 18 minutes	
Normal consistency		Water/cement ratio =0.30	NBR 7215 (ABNT, 1995)
Fineness (% retained on sieve # 200)		1.62	MB 3432 (ABNT, 1991)
Unit weight (g/cm^3)		1.45	NBR 7251 (ABNT, 1982)
True density (g/cm^3)		3.09	NM 23 (ABNT, 1998)
Compressive strength (MPa) at day 28		34.7	NBR 7215 (ABNT, 1995)

Table 2 - **Physical characteristics of quicklime powder dolomitic**

Determination	Result	CV-C limits	Method
Unit weight (g/cm^3)	0.96	-	NBR 7251 (ABNT, 1982)
True density (g/cm^3)	3.10	-	NM 23 (ABNT, 1998)
Fineness (% retained) Sieve # 30 Sieve # 200	 0.7 0.22	 ≤ 5.0 ≤ 30	NBR 9289 (ABNT, 2000)

Table 3 - **Physical characteristics of the fine aggregate - fine washed river sand**

Determination	Result		Method
Unit weight (g/cm^3)	1.55		NBR 7251 (ABNT, 1982)
True density (g/cm^3)	2.63		Pycnometer
Particle size distribution	Sieve (mm)	Accumulated % retained	NBR 7217 (ABNT, 1987)
	2.4	0	
	1.2	1	
	0.6	7	
	0.3	67	
	0.15	99	
	Max. dimension (mm)	1.2	
	Fineness module	1.74	

Table 4 - **Chemical characteristics of the rubber powder - weight in mg.kg^{-1} - analysis - atomic absorption spectrometry**

Fe	Cu	Mn	Zn	Pb	Cd	Cr (total)	Ni
710.00	52.60	-	646.00	108.00	-	32.00	4.00

Table 5 – **Physical characteristics of the rubber powder**

Determination	Result		Method
Unit weight (g/cm^3)	0.44		NBR 7251 (ABNT, 1982)
True density (g/cm^3)	0.79		Pycnometer
Particle size distribution	Sieve (mm)	Accumulated % retained	NBR 7217 (ABNT, 1987)
	1.2	0	
	0.6	0	
	0.3	34	
	0.15	99	
	Max. dimension (mm)	0.42	
	Fineness module	1.33	

Mortar

The simple mortar was produced in a 1:6 proportion of lime and sand (by volume) with 2.46 dm^3 of water per kg of lime and divided into two equal parts. The first part was packed in plastic bags and the second in covered metal recipients. Both parts were then ripened for seven days with their weights determined.

The first part of the mortar received cement composing the proportion 1:1.5:9 (cement, lime, and sand, by volume) - 1:0.993:9.623 in equivalent weight - and the addition of rubber powder contents of 6%, 8%, 10%, and 12% relative to the volume of aggregate. Reference mortar was named as Am0, and Am6, Am8, Am10, and Am12 were named according to the percentage of rubber powder used. Amx refers to all the series.

The second part of the mortar was subjected to drying in an oven at a temperature of (105 ± 10) °C until constant weight. The dry mortar weight was determined and the procedure was carried out as in Canova (2002), with storage for a period of 60 days. Cement and rubber powder were then added in the same proportions as for the first mortar. The same naming procedure was followed for this mortar, only replacing the letter "m" with the letter "s".

Measured properties

The properties were evaluated via laboratory testing according to ABNT (Brazilian Technical Standards Association). The axial compressive strength, the deformation energy, the void content, and the water absorption by capillarity were all evaluated in cylindrical specimens with 5 cm in diameter and 10 cm in height and tested at day 28. The flexural strength and the restrained shrinkage were evaluated in prismatic specimens. The tensile bond strength of the substrate was also evaluated.

- *Axial compressive strength* – it was measured according to procedures of NBR 13279 (ABNT, 1995) and NBR 7215 (ABNT, 1995).

- *Flexural strength* – the procedure was adapted from the ISO/DIS 679:1993. Molds measuring 200 mm in length, 75 mm in width, and 25 mm in depth were used in triplicate. The tests were performed at day 28 with the application of a uniformly distributed load on the middle cross section of the bi-supported specimen. The tensile stress in bending is given by Equation 1, where:

$$\sigma = 1.5\ PL/bd^2 \qquad \text{Eq. 1}$$

σ = tensile stress in bending (MPa);

P = load applied in the middle of the prism (N);

L = distance between supports (160 mm);

b = larger side of the specimen cross section (mm);

d = specimen depth (mm).

The 160 mm distance between the supports of the specimen was the same as in ISO/DIS 679 (ISO, 1993). A load application rate of 0.02MPa/s was also adopted, as in Canova (2002), due to the low strength values obtained for this mortar.

- *Deformation energy during compression* – the measurement was evaluated by the area under the tension vs. deformation curve in compression tests run in a simple compression machine.

- *Void content* – the analysis was based on the NBR 9778 (ABNT, 1987) procedure.

- *Water absorption by capillarity* – the measurement was based on the NBR 9779 (ABNT, 1995) procedures, but changes in the reading times were needed – chosen times were as follows: every 10 minutes up to minute 90, every 15 minutes from minute 90 to 150, every 20 minutes from minute 150 to 360, every 45 minutes from minute 360 to 450, and every 60 minutes from minute 450 to 1350. Marks were made every 1 cm high in the specimen to monitor its surface moisture. These marks were made along three generatrixes to facilitate the reading.

- *Drying retraction with one restrained side* - in this experiment, where specimens were used as coating simulation, the influence of the base on the

water loss to filter paper and on the adhesion of the mortar on the metal grid was simulated.

The procedure used was similar to that of Lejeune (1995). This kind of experiment was accomplished to observe the restrained shrinkage, which is the deformation measured in mortar immediately after demolding. Specimens measuring 285 mm in length, 100 mm in width, and 25 mm in depth were used in triplicate. The metal grid used for mortar adhesion was 1 mm thick, drilled with 15 mm diameter round holes in approximately 50% of its area, with 3 mm spacing between them. Filter paper was used between the base and the metal grid, allowing water suction and mortar demolding.

Retraction measures were performed on the free, exposed to air upper side of the specimen. The specimens were kept in a dry chamber with temperature of (23±2) °C and relative humidity of (50±4) %. Readings were taken every 24 hours up to day 10, and then at days 13, 16, 21, and 28.

- *Tensile bond strength* – it was determined for specimens on substrate according to NBR 13528 (ABNT, 1995). The used substrate was made with a 9 x 14 x 19 cm 6-holed ceramic block with application of an adhesion layer in a 1:3 proportion of cement and sand (by volume). The plastering was made in 1.0 m^2 panels, in 1.5 cm thick single layers, for each one of the rubber powder contents. The determination was made at day 91.

Results and discussion

The consistency index, specified by NBR 13276 (ABNT, 1995) between 245 and 265 mm of scattering, was determined with the flow table test. The results, presented in Table 6, characterized the workability of each mixture and identified them as suitable for application as plastering mortars.

Comparing the axial compressive strengths

In Fig. 1, the same trend of reduced compressive strength is observed for both mortars, though it was more pronounced for the ripened mortar as compared to the oven-dried mortar. The difference was close to 4% for the reference mortar and reached 14% for the mortars with 12% of rubber powder.

Table 6 - **Proportion parameters of the mortars**

Mortar	Consistency index 255 ± 10 (mm)	Water/dry materials ratio (mass)	Water/cement ratio (mass)	Water/binders ratio (mass)
Am0	257	0.250	2.89	1.435
Am6	255	0.235	2.77	1.370
Am8	254	0.234	2.77	1.370
Am10	260	0.233	2.77	1.370
Am12	250	0.232	2.77	1.370
As0	254	0.231	2.64	1.328
As6	250	0.226	2.60	1.303
As8	252	0.224	2.60	1.289
As10	253	0.223	2.60	1.289
As12	251	0.222	2.60	1.289

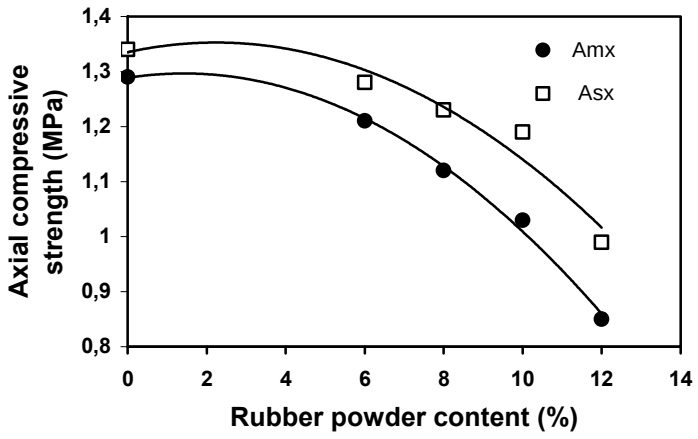

Figure 1 - **Axial compressive strength for mortars Amx (●) and Asx (□)**

The lower water/binders ratio and the lower water demand for the oven-dried mortar to return to the plastic state, contributed to the increased axial compressive strength. The still lower water/binders ratio for the mortars with rubber powder addition led to a progressive increase in the difference in strength between the two mortars with the same level of addition.

The rubber powder was used in mortar as an addition to the aggregate volume that has increased the volume of mortar in the plastic state relative to the reference mortar and contributed to a further reduction in axial compressive strength. This contribution was found to be of 2%. In considering this difference, it was observed that the strength of the oven-dried mortar with 8% rubber powder practically equaled the strength of the reference mortar. It was verified, though, that the major influence on the reduction in axial compression strength was from the low specific gravity of the rubber.

Comparing the flexural strengths

One can see in Fig. 2 that the flexural strength was also higher for the oven-dried mortar than for the ripened mortar. This increase is due to the reduced water/cement ratio of the oven-dried mortar when compared with the ripened mortar. It is assumed that the air incorporated into the dry mixture and the air trapped inside the grains, as well as the non-total water absorption of the grains, contributed to that reduction. The increase in flexural strength was of 5% for the oven-dried mortar with a rubber powder content of 6%, but reached 11% in the mortar with a rubber powder content of 12%.

Comparing the deformation energies during compression

Comparing the deformation energies in Table 7, one can observe that the energy calculated for the 1.5 MPa stress was greater in the mortars with added rubber powder, proving the greater elastic energy of rubber.

The oven-dried mortar presented, for the same stress, higher deformation energy values than the ripened mortar. This was observed in the reference mortar as well as in the mortars with rubber powder addition. However, although the oven-dried mortar presented higher final strengths, there was a change in its internal structure, showing greater deformation than the ripened mortar.

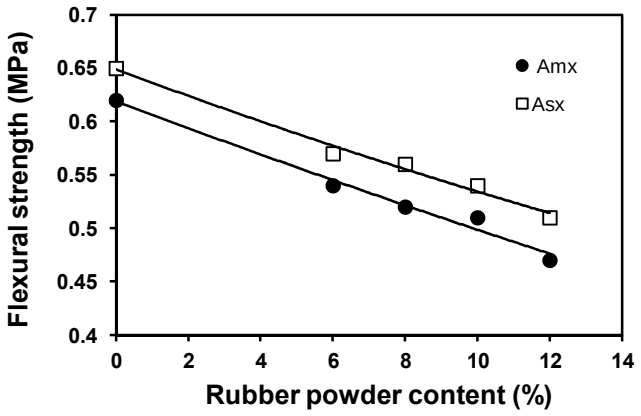

Figure 2 - **Flexural strength for mortars Amx (●) and Asx (□)**

Table 7 – **Mortar deformation energy test results**

Mortar	Deformation energy during compression (MPa.mm)
Am0	0.00689
Am6	0.00726
Am8	0.00731
Am10	0.00731
Am12	0.00749
As0	0.00814
As6	0.00834
As8	0.00865
As10	0.00886
As12	0.00937

Comparing the void contents at (105±10) °C

Through the analysis of Fig. 3, one can verify that the oven-dried mortar showed a better reduction in the void content than the ripened mortar as rubber was added, thus closing the pore structure of the mortar. This is related to the greater reduction in the water/binders ratio of the oven-dried mortar.

Comparing results of water absorption by capillarity

One can observe in Fig. 4 that the oven-dried mortar absorbed less water by capillarity than the ripened mortar. This was observed in the reference mortar as well as in the mortars with rubber powder addition. A significant difference was observed for the mortars with 10% and 12% of rubber powder, as even the time in which water reached the top of the specimen was increased, while the specimen containing 8% of rubber powder presented the largest time to have its top reached by water.

The observed reduction in the capillarity rate was due to the lower porosity of the material, which occurred as the addition of rubber powder increased the amount of fine aggregate and reduced the water/binders ratio, with more extensive closure of the pores for the oven-dried mortars.

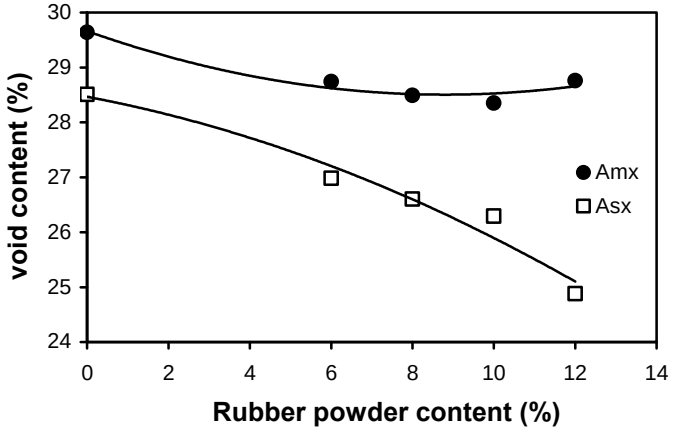

Figure 3 - **Void contents for mortars Amx (●) and Asx (□) at (105±10) °C**

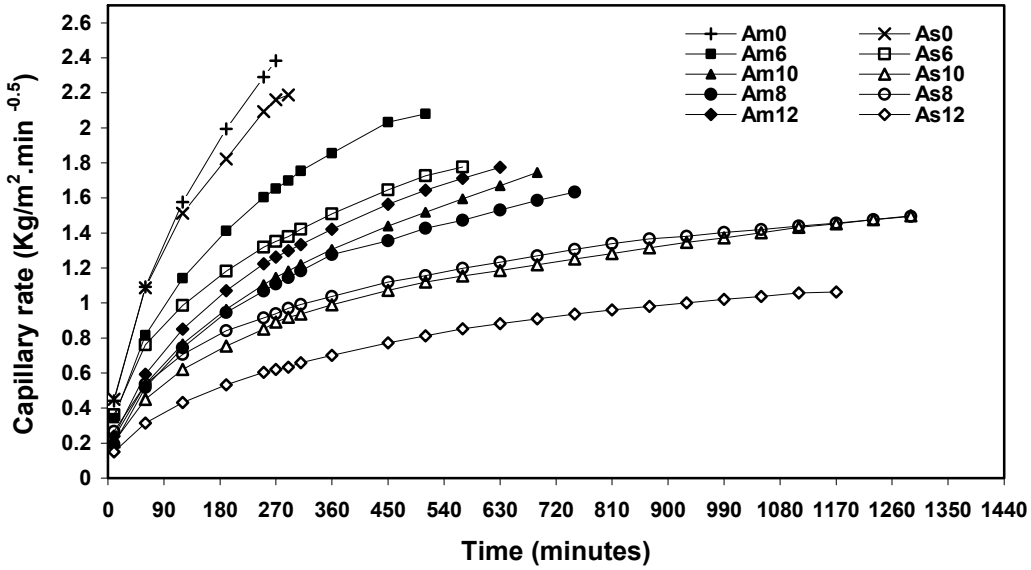

Figure 4 - **Water absorption by capillarity for mortars Am0 (+), As0 (×), Am6 (■), As6(□), Am8(○), As8(●), Am10 (▲), As10 (Δ), Am12 (♦) and As12(◇)**

Comparing the restrained shrinkages

One can see in Fig. 5 that the oven-dried mortar presented lower restrained shrinkage than the ripened mortar. This was observed in the reference mortar as well as in the mortars with rubber powder addition. The difference between the oven-dried and the ripened reference mortars was of about 17% from day 4 to day 28 after demolding. For the mortars with rubber powder, there was no significant difference up to the third day after demolding. However, at day 4, the shrinkage of the oven-dried mortar was 6% lower than that of the ripened mortar, and at day 28 this difference went beyond 16%.

The greater concentration of fine aggregate, with the addition of rubber powder, and the reduction in the water/binders ratio (especially for the oven-dried mortar) are factors that contributed to a lower retraction of the mortar and a reduction of the negative effects of an accelerated drying. One could suppose that the reduction in drying retraction is an indication of a possible plastic retraction of the mortars.

Comparing the tensile bond strengths

One can see in Fig. 6 that the tensile bond strength values were similar for the oven-dried and the ripened reference mortars. The same pattern was observed for mortars with 6% and 10% of rubber powder. However, for 8% of rubber powder the ripened mortar had a 5% lower strength than the oven-dried one, and for 12% of rubber powder this difference was of 9%. This trend of increasing tensile bond strength for oven-dried mortars from 8% addition of rubber powder may have occurred because of the increased mechanical strength achieved by these mortars.

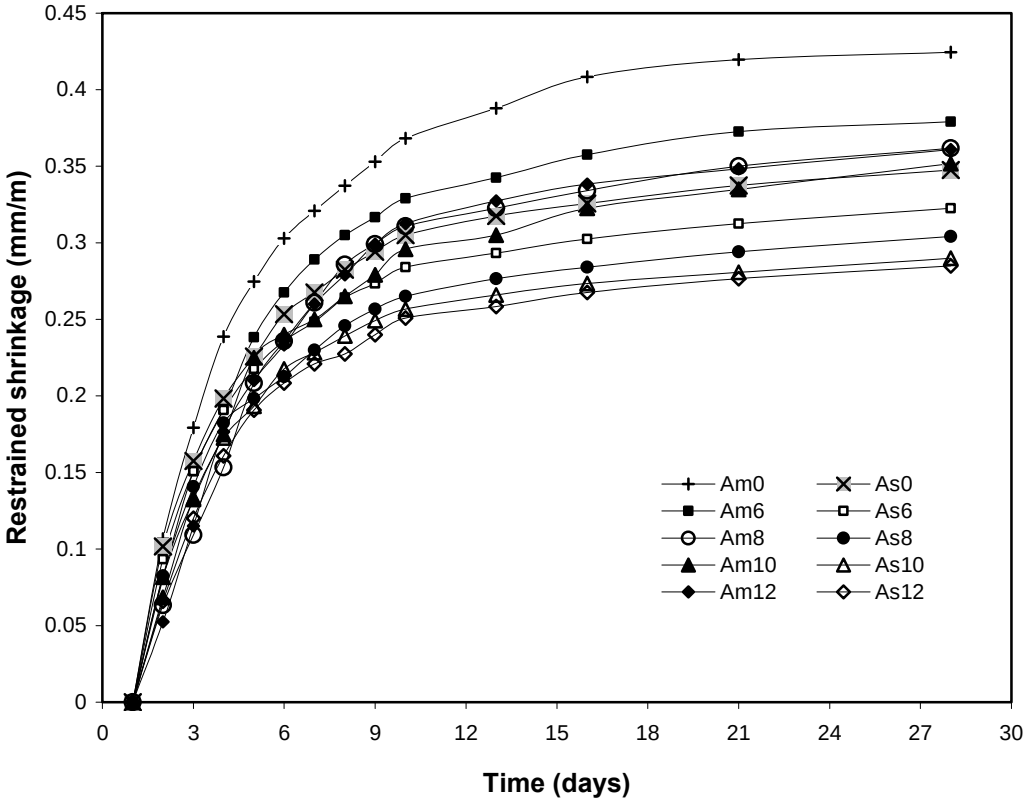

Figure 5 - **Restrained shrinkage for mortars Am0 (+), As0 (×), Am6 (■), As6 (□), Am8 (○), As8 (●), Am10 (▲), As10 (Δ), Am12 (♦) and As12 (◇)**

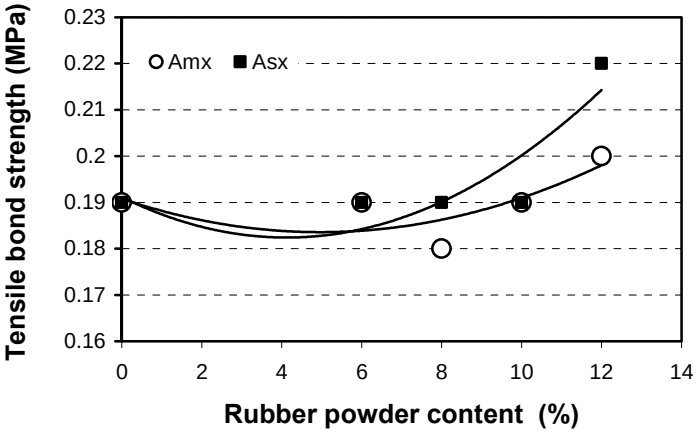

Figure 6 - **Tensile bond strength for mortars Amx (○) and Asx (■)**

Conclusion

The addition of rubber powder in the mortars resulted in lower compressive and flexural strengths, but contributed to higher deformation energies. However, there was no statistically significant difference in the strengths for an addition of 6% in the ripened mortar or up to 10% in the oven-dried mortar.

The rubber powder addition improved the void content, the water absorption by capillarity and the drying retraction, with better results for the oven-dried mortar, particularly regarding water absorption by capillarity. As for tensile bond strength, no significant variation was observed for both mortars.

In general it is concluded that the production of rendering mortar with rubber powder addition is fully feasible up to a rubber powder content of 8% in the case of the oven-dried mortar. When using the ripened mortar, it is better not to exceed a content of 6%.

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